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## XV.

ON THE ELECTRICAL RESISTANCES OF CERTAIN  
POOR CONDUCTORS.

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Presented October 10, 1894.

SINCE the subject of electricity began to be studied seriously, many experimenters have made lists of substances arranged in the order of their electrical conductivities. These lists have not agreed with one another in all respects; but at one end of every one of them metals have stood, and at the other end such insulating substances as ebonite, glass, paraffine, shellac, and mica. Somewhere between these extremes have appeared the so called "half-conductors,"\* like wood and some kinds of stone. How these latter are to be classed depends very much, of course, upon the uses to which they are put. For work with the small charges and high potentials of experiments in electrostatics, we must generally consider wood as a conductor; while, for practical purposes, we may regard the wooden base upon which a telegraph instrument is mounted as a perfect insulator.

In making electrical measurements in the laboratory, it is often necessary to be able to change quickly the connections of one's apparatus, and for this purpose some kind of "switch-board" must generally be provided. Sometimes a dry wooden board, into which holes have been bored to form mercury cups, will suffice; sometimes a plate of ebonite or a non-combustible slab of slate or marble is required.

I have been obliged, during the last three years, to procure several hundred more or less complicated switch-boards, and many of these had to be used in making accurate measurements of electrical quantities. It has been necessary, therefore, to determine under what circumstances hard dry wood or red vulcanized fibre may safely be used, and when marble or ebonite, or even a block of freshly scraped paraffine, is required. For use with these switch-boards I have provided several hundred resistance coils of German silver, platinoid,

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\* Du Moncel, *Annales de Chimie et de Physique*, [5.], X. 1877; Addenbrooke, Muir and Jamieson's *Pocket-Book*, p. 194.

and manganine wire, wound on spools two inches in diameter over all, and from four to eight inches long. The coils are furnished with stout copper terminals (Figure 1), and are protected by cylindrical shields made of brass or pasteboard tube. The copper terminals are screwed, with axes parallel to each other, and one inch apart, into one end of each spool. Spools and shields together act as shunts to the coils, and it has been necessary to determine a lower limit for the resistance which such a shunt could offer in practice. It has been necessary also to measure the insulation resistance between the two mercury cups, on a switch-board, into which the terminals of one of the resistance coils dip. These cups are formed by holes three eighths of an inch in diameter (Figure 2), and five eighths or three quarters of an inch deep. The axes of each pair of holes are one inch apart. The holes are bored, or drilled, in a lathe, in the top of the switch-board, with a Förstner bit if the material be wood or vulcanized fibre or ebonite, with a flat or twist drill moistened with water if slate or marble be used.

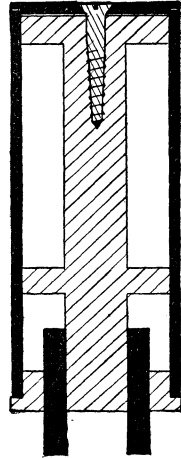


FIG. 1.

In order to get such information as I needed with respect to the insulation resistance which might safely be counted on in the case of wood, marble, or vulcanized fibre, used for the purposes just described, I made a long series of measurements, with the help of a battery of twelve dry cells, and an absolutely calibrated high-resistance mirror galvanometer, on a large number of specimens. Of course individual measurements of this sort have little general value, but a large number of experiments on different samples of material of a given kind make it possible to set a lower limit to the resistance of this substance when used in a given way, and such knowledge as this is often useful when one is planning apparatus.



FIG. 2. For instance, my experience seems to show that it is perfectly safe to assume that the specific resistance per cubic centimeter of an inch-thick slab of pure white Vermont marble, which has been standing exposed to the air in a fairly dry room for three weeks, is not less than  $10^9$  ohms, and is probably as much as  $10^{10}$  ohms. Really dry white marble has a far higher specific resistance than this. It is safe also to set a lower limit for the specific resistance of sea-

soned wood of a given kind, but only in the sense that wood of resistance as high as this can always be obtained without difficulty in the market. Abnormal specimens occur. In measuring the insulation resistances between the copper terminals of unparaffined maple and birch spools, like or similar to the one represented in Figure 1, I experimented upon a large number of spools which had been lying for about a year in a certain dry closet. The smallest resistance in any case was 1,100 megohms, and the average resistance was more than 2,000 megohms. This is what one may expect to get in spools of this kind. In the same closet were some spools of a different lot, bought of the maker of the other spools, and in no way different in appearance from them. These also had been seasoning beside the others for a year, yet the average insulation resistance of these spools was only a little over one megohm. This is an extreme case. The nearest approach to it that I found in experimenting on other lots of spools was that of some which had been standing for a long time in the damp basement of the laboratory, and represent what the ordinarily good dry spool might become if it were placed for months in a moist place. Yet the lowest resistance in the case of these spools was more than 100 megohms.

It is, of course, well known that the insulation resistance of a porous half-conductor depends very much upon the amount of moisture which it contains, and that this moisture may give rise to all manner of anomalies, as Du Moncel has shown. Thus, white marble when it comes from the mill is often a fairly good conductor, owing to the water which it has absorbed in the process of manufacture, but a fortnight's drying in the sun sometimes increases its resistance ten thousand fold. It is now almost always possible to get kiln-dried wood, and after wood or marble has once been thoroughly dried, an immersion in a bath of hot paraffine tends to prevent the reabsorption of moisture. Red vulcanized fibre absorbs hot paraffine greedily; but I do not think that it would be easy to saturate a piece of fibre so thoroughly with paraffine that a drop of water allowed to rest on its surface for a few moments would not begin to raise a blister.

Prolonged immersion in clean, hot, melted paraffine always increases the insulation of a half-conductor, even if the bath leaves no perceptible coating on the outside. This increase, however, is very slight in the cases of some close-grained substances like rosewood, though it may amount to three or four times the original resistance in the case of a porous conductor. If while such a conductor is immersed in hot paraffine the bath and its contents be placed under the receiver

of an air-pump, and the air be alternately exhausted from and re-admitted to the receiver, the resistance of the conductor is always materially increased. This process is in common use for the purpose of improving the insulation between the layers of covered wire in galvanometer coils. A coat of shellac, when not thoroughly dry, often lowers very much the insulation resistance of a porous half-conductor.

The following table shows the results of measurements of the resistance between the two members of each of a large number of pairs of mercury cups of the size shown in Figure 2 bored in the tops of slabs of different substances. The specific resistance of wood for currents going across the grain is generally from 20 to 50 per cent higher than for currents going with the grain. The figures given below may be taken as referring to currents going with the grain. I procured, wherever I could conveniently, a number of pieces of seasoned wood of each variety named, rejecting none, and I believe that the numbers in the table represent fairly what one may expect in practice. The number in the second column of the table, in the same horizontal line with the name of a substance, shows how many pairs of mercury cups bored in slabs of this substance were experimented on, while the numbers in the next two columns give in megohms the lowest and the average resistance between the members of these pairs. Sometimes a single pair of cups only was bored in a slab, sometimes two or three. The resistances between the members of pairs of mercury cups bored in the single specimens of cypress and maple that I had were, in the average, upwards of 2,000 megohms.

TABLE I.

Substance.	No. of Pairs of Cups.	Lowest Resistance in Megohms.	Average Resistance in Megohms.
Ash . . . . .	13	550	920
Cherry . . . . .	15	1100	4000
Mahogany * . . . .	14	430	730
Oak . . . . .	17	220	420
Pine . . . . .	24	330	630
Hard Pine. . . . .	8	10	48
Black Walnut . . .	30	1100	3000
Red Fibre . . . . .	6	2	4

Choice pieces of wood of each of the seven kinds named in the table would yield insulation resistances far higher than those given in the column of averages, and not less than 1,000 megohms even in the case of hard pine.

TABLE II.

Substance.	Lowest Specific Resistance in Megohms found among the Specimens tested.	Average Specific Resistance in Megohms of the Specimens tested.
Ash . . . . .	380	700
Cherry . . . . .	2800	6000
Mahogany . . . .	310	610
Oak . . . . .	1050	2200
Hard Pine . . . .	17	1050
White Pine . . . .	360	1470
Black Walnut . .	320	2100
Vulcanized Fibre .	3	60
Slate . . . . .	184	280
Soapstone . . . .	330	500
White Marble . .	2000	8800

Table II. gives the results of a great number of experiments upon the electric resistances of slabs of different substances, through which currents were sent by means of mercury electrodes placed opposite each other. Each electrode was contained in a cavity excavated in a

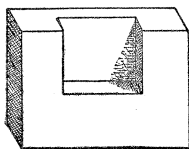


FIG. 3.

piece of ebonite (Figure 3), and was generally about 60 square centimeters in area. Comparative measurements made with slabs of wood cut across the grain were rather unsatisfactory, for the reason that there seemed to be in every case a resistance of contact (*Uebergangswiderstand*) at the common surface of the mercury and wood, and

the magnitude of this resistance depended very much upon the roughness or smoothness of the cut, and was sometimes greater than the intrinsic resistance of the wood. In experiments made with currents sent across the grain of the wood through slabs of different thicknesses cut from the same plank, the resistances seemed to follow

Ohm's law so nearly that the contact resistances were of comparatively small importance. The contact resistance between two pieces of wood pressed together seemed to be great, since the insulation resistance of a compound slab formed of two in close contact was far greater than the sum of the resistances of the two taken singly. To avoid any disturbing effects that might arise from injury to the substance at tool-cut edges, slabs were sometimes used (see the shaded portion of Figure 4) much greater in area than the electrodes, and this necessitated the making of allowances (based on experiments with zinc electrodes in a tank of solution of zinc sulphate) for the effect of the spreading of the lines of flow in the slab.

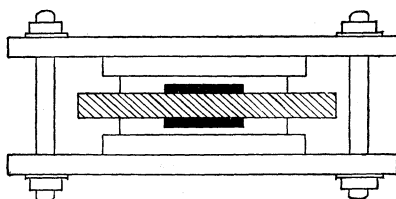


FIG. 4.

This process was not entirely satisfactory, but the results are doubtless quite accurate enough for the purpose in view. The mercury electrodes were effectively insulated from the brass clamping bolts by the intervening slabs of ebonite.

All the slabs of stone were specially dried in the summer sun for about three weeks before they were experimented on. Through the kindness of Messrs. Bowker, Torrey, & Co. of Boston, I was enabled to test the specific resistances of a large number of pieces of colored marble of different kinds. A vein in a piece of marble used as a switch-board has been known to short-circuit a fire-alarm system, and it was to be expected that the specific resistances of most colored marbles would prove to be less than that of white marble. In one instance, the specific resistance was as low as three megohms. The single piece of sandstone which I had at my disposal had been in a dry place in the laboratory for more than five years; its specific resistance was thirty megohms. The average specific resistance of hard pine as given in Table II. means little. I have seen a piece of this wood with a specific resistance as high as 4,000 megohms; but very resinous pieces of hard pine, however long they may have been dried, seem to have low specific resistances. Some thin birch, of the kind now used to separate from each other the successive plates of one or two forms of storage cell, had a specific resistance, when dry, of about 500 megohms.